

## Magnetic Reconnection Instabilities in Soft-Gamma Repeaters

Jeremy S. Heyl and Ramandeep Gill

*Department of Physics and Astronomy, University of British Columbia, Vancouver BC Canada*

We examine an external trigger mechanism that gives rise to the intense soft gamma-ray repeater (SGR) giant flares. Out of the three giant flares, two showcased the existence of a precursor, which we show to have had initiated the main flare. We develop a reconnection model based on the hypothesis that shearing motion of the footpoints causes the materialization of a Sweet-Parker current layer in the magnetosphere. The thinning of this macroscopic layer due to the development of an embedded super-hot turbulent current layer switches on the impulsive Hall reconnection, which powers the giant flare. We show that the thinning time is on the order of the pre-flare quiescent time.

### 1. Preliminaries

We take the observation that two of the three giant flares from the SGRs were preceded by a precursor that was similar in energy ( $\sim 10^{41}$  erg) to a typical short SGR burst (Ibrahim et al. 2001; Hurley et al. 2005) as a hint that the precursor “lights the fuse” for the giant flare. The natural timescale for this fuse is the Alfvén time of the inner magnetosphere, which for exceptionally low values of the plasma beta parameter is very small;  $\tau_A \sim R_*/c \sim 30\mu s$ . Although this is close to the rise time of the flare, this timescale is up to six orders of magnitude shorter than the delay between the precursor and the flare. Of course, the symmetries of the magnetic field coupled to the plasma prevent the quasi-steady-state configuration to change this quickly unless the gradient of the magnetic field are large. So, the questions are how does the field develop large gradients and can this happen on the timescale of the delay between the precursors and the giant flares.

Figure 1 outlines a scenario where the initial SGR flare which is associated with a crustal shift injects a twist in the magnetosphere (Thompson & Duncan 1995). This causes the external magnetic field lines to form a configuration allowing the formation of a current sheet where the field lines can reconnect and release a large amount of magnetic energy (see for e.g. Lyutikov 2006).

This reconnection will proceed slowly over a resistive timescale. The standard picture for this process is the Sweet-Parker layer denoted in Figure 1 and placed into focus in the left panel of Figure 2. We assume that the plasma is incompressible and that the magnetic energy is converted to kinetic energy. Combining these assumptions with the geometry then yields a relationship between the Alfvénic Mach

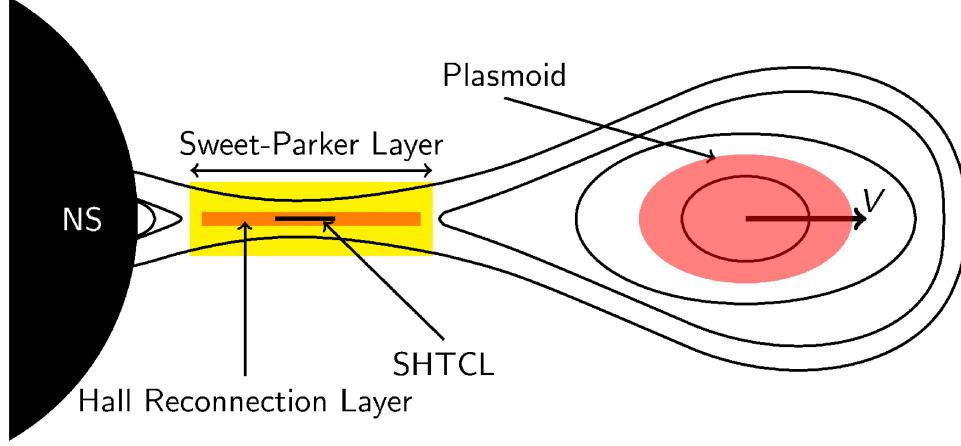


Fig. 1. This figure displays the setup of the different reconnecting current layers. The macroscopic Sweet-Parker layer with length  $L \sim 10^5$  cm and width  $\delta \sim 0.01$  cm is the largest of the three. This layer is then thinned down vertically as strong magnetic flux is convected into the dissipation region. The Hall reconnection layer, represented by the dark gray region, develops when  $\delta$  becomes comparable to the ion-inertial length  $d_i$ . The system makes a transition from the slow to the impulsive reconnection and powers the main flare. The tiny region embedded inside the Sweet-Parker layer is the super-hot turbulent current layer, which aids in creating sufficient anomalous resistivity to facilitate the formation of the Sweet-Parker layer. The strongly accelerated plasma downstream of the reconnection layer is trapped inside magnetic flux lines and forms a plasmoid moving at some speed  $V$ . This plasmoid is then finally ejected during the initial spike when the external field undergoes a sudden relaxation (After Lyutikov 2006).

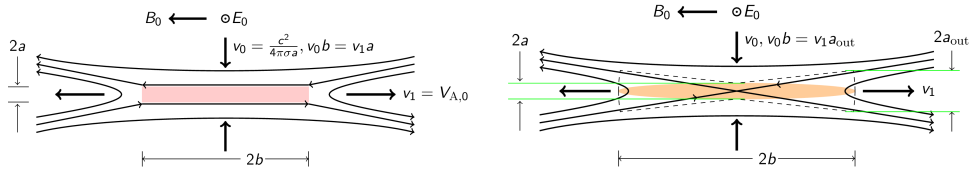


Fig. 2. This figure focusses on the two reconnection regions. The left panel is the Sweet-Parker layer, and the right panel is the Super-Hot Turbulent-Current Layer (SHTCL). See Somov (2006) for further details.

number of the reconnecting flow and the resistivity through the Lundquist number,

$$M_A = \frac{v_0}{V_{A,0}} \sim \left( \frac{c^2}{4\pi\sigma b} \right)^{1/2} = N_L^{-1/2}. \quad (1)$$

Because the Spitzer resistivity of the collisionless plasma at temperatures  $\sim 10^8$  K is small, this Mach number is small, and the reconnection timescale is large unless some sort of anomalous resistivity is present. We will use the super-hot turbulent current layer (SHTCL) model to introduce a source of anomalous resistivity (Somov 2006). Again making the same assumptions as with the Sweet-Parker layer but with the modified geometry of the right panel of Figure 2, we obtain the reconnection

velocity of

$$M_A = \frac{v_0}{V_{A,0}} \sim \frac{a_{\text{out}}}{b} \sim \frac{B_{\perp}}{B_0} \quad (2)$$

which now depends on geometric considerations rather than the Spitzer resistivity of the plasma.

What length scales do we have? From biggest to smallest, we have the layer width ( $b$ ), the layer funnel width ( $a_{\text{out}}$ ), the layer thickness ( $a$ ), the proton cyclotron radius, and the electron cyclotron radius. Cassak et al. (2006) show that the Sweet-Parker layer can be thinned down to proton cyclotron lengthscale by convecting strong fields into the current layer. We find the critical field strength for this to occur  $B_c \sim 10^{14}$  G. With the presence of baryons the thinned current layer undergoes Hall reconnection which proceeds on an Alfvénic timescale, hundreds of microseconds typically. Thus, the delay between the precursor to the flare is the timescale to thin from the initial reconnection region (this determines the total energy of the flare) to the proton cyclotron radius.

## 2. Conclusions

The thin SHTCL provides anomalous resistivity that allows the current layer to thin on a timescale comparable to the delay for the December 27 event

$$\tau_{\text{thin}} \sim 2W_s \sqrt{\frac{L}{\eta_{\text{diff}} c} \left( \frac{B_c}{B_0} \right)} \quad (3)$$

$$\sim 130 \text{ s} \left( \frac{W_s}{10^5 \text{ cm}} \right) \left( \frac{L}{10^5 \text{ cm}} \right) \left( \frac{B_0}{10^{14} \text{ G}} \right)^{-1/2} \left( \frac{n_b}{6 \times 10^{22} \text{ cm}^{-3}} \right)^{3/4} \quad (4)$$

where  $W_s$  is the magnetic field shear length,  $L$  is the length of the current sheet,

$$n_b \sim 6 \times 10^{22} \left( \frac{E_{\text{th}}}{10^{38} \text{ erg}} \right) \left( \frac{R_{\star}}{10^6 \text{ cm}} \right)^{-2} \left( \frac{M_{\star}}{1.4 M_{\odot}} \right) \text{ cm}^{-3} \quad (5)$$

We have used the data for the December 27 event. The August 27 flare had a short and weak precursor, yielding about one percent of the baryons. Furthermore, the flare was weaker too, requiring a smaller reconnection region. We get

$$\tau_{\text{thin}} \sim 0.4 \text{ s} \left( \frac{W_s}{2 \times 10^4 \text{ cm}} \right) \left( \frac{L}{5 \times 10^4 \text{ cm}} \right) \left( \frac{B_0}{10^{14} \text{ G}} \right)^{-1/2} \left( \frac{n_b}{6 \times 10^{20} \text{ cm}^{-3}} \right)^{3/4} \quad (6)$$

similar to the delay for the August 27 event. Future giant flares from SGRs will improve our understanding of such correlations as well as the mechanism for the triggering of giant flares from soft-gamma repeaters.

## Bibliography

- Cassak P. A., Drake J. F., Shay M. A., 2006, ApJL, 644, L145  
 Gill R., Heyl J. S., 2010, MNRAS, 407, 1926

Hurley K., et al., 2005, *Nature*, 434, 1098

Ibrahim A. I., et al., 2001, *ApJ*, 558, 237

Lyutikov M., 2006, *MNRAS*, 367, 1594

Somov, B., 2006, *Plasma Astrophysics, Part II : Reconnection and Flares*, Astrophysics and space science library (ASSL), Vol. 341. Dordrecht: Springer

Thompson C., Duncan R. C., 1995, *MNRAS*, 275, 255